

Influence of technological depressurization on the operation of a cascade pneumatic separator

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Abstract. The article is devoted to assessing the impact of the technological depressurization of the powdered material dispenser on the work of the cascading pneumatic separator. The results of laboratory tests are presented. The article states that the magnitude of effectiveness and the separation boundary of powdered materials are reduced when working with a depressurized dispenser. The mathematical model of the cascading separator and the results of the computer experiment are presented. The article presents the dependence of the quantity of the product and the content of fine particle classes in the finished material on the amount of relative air flow through the powdered dispenser of the initial product. The change in the granulometric composition of the enriched quartz sand received is shown, depending on the amount of relative air consumption through the powdered dispenser at a fixed air velocity through the upper part of the separator. It was found that the maximum relative speed of air flow through the powder dispenser should be no more than 10–15 %.

1. Introduction

The factional processes of bulk materials in pneumatic separators are widely used in mineral enrichment [1–7]. Cascade classifiers are the most effective [7–8] because they are made of identical successive elements in the form of different sloping shelves, cones and impellers. Re-cleaning of powdered products consistently occurs in each of these cascades.

Each powdery materials separation system consists of the powdered dispenser, cyclones and a bunker with coarse material. The main problems of tightness arise in the powdered dispensers of the source material.

Unauthorized movement of air flow through the powder dispenser disrupts the operation of the separator. The flow rate of gas decreases in cascades below the powdered dispenser.

Determining the effect of the technological depressurization of the powdered dispenser on the magnitude of effectiveness of a cascading pneumatic powder separator is an urgent task.

2. Experiment

A laboratory experiment was conducted to assess the impact of technological depressurization in the powdered dispenser on the efficiency of the separator. During the experiment, a cascading separator was studied with the delivery of the initial product to the central section. The separator consisted of three cascading sections above and three cascading sections under the powdered dispenser. Each cascade consisted of an impeller and a perforated cone (Figure 1).

The experiment explored the possibility of obtaining enriched sand 0–5 mm with the minimization of dust fraction minus 0.16 mm in a cascading separator. The fractionation process was carried out at three different air flow velocities through an airtight installation and a depressurization powdered dispenser. In each series of experiments, the velocity flow was measured in the lower section of the



device and in the powdered dispenser using a thermoanemometer. Total air flow was determined by a normal diaphragm located after cyclone. The relative air flow through the powdered dispenser in the experiments ranged from 6 to 23 %, while the rate of air velocity in the lower sections of the classifier ranged from 3 to 25 %.

The experiment showed that when the powdered dispenser is depressurized, the separation boundary and the overall effectiveness of fractionation of the bulk material is reduced (Figure 2, Table 1).

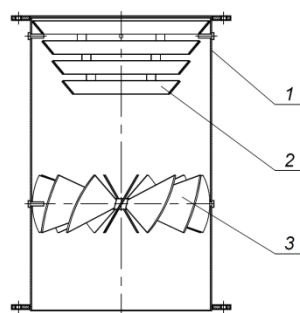


Figure 1. Single stage separator: 1–Housing, 2–multi Cone, 3–Impeller.

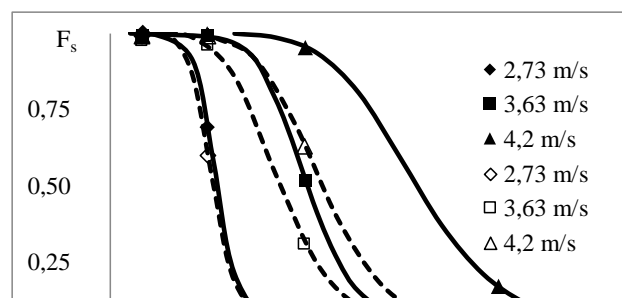


Figure 2. Functions of fractional separation at different air velocity: solid lines–separator without depressurization; dotted lines – with depressurization.

If the granulometric compositions of fine $r_s(x_i)$, coarse $r_L(x_i)$ and $r_B(x_i)$ material is known, the functions of fractional extraction for different w modes can be calculated [9–11]. If they are approximated to the Plitt function [12], the dependence of the airflow velocity through the classifier on the main characteristics of the fractionation process can be detected – the separation boundary x_{50w} and the sharpness p_w of separation. The fractional composition of the separation products is represented in Table 1.

Table 1. Fractional composition.

Sieve, mm	Source Material	A coarse product with an airtight feeder			A coarse product with a non-sealed feeder		
		2.73 m/s	3.63 m/s	4.2 m/s	2.73 m/s	3.63 m/s	4.2 m/s
5.00	0.07	0.07	0.09	0.10	0.07	0.08	0.09
2.50	23.11	26.62	31.12	37.12	26.34	29.49	32.16
1.25	16.84	19.40	22.67	27.00	19.19	21.49	23.43
0.63	25.66	29.56	34.32	34.42	29.25	32.47	34.93
0.32	17.97	20.61	11.72	1.35	20.37	15.90	9.28
0.16	10.36	3.73	0.08	0.01	4.78	0.56	0.11
–	6.00	0.00	0.00	0.00	0.00	0.00	0.00

Formula for the relative velocity of air flow through a depressurized dispenser:

$$\bar{V} = \frac{V_d}{V}, \quad (1)$$

the relative separation boundary of the division will be defined as:

$$\bar{x}_{50} = \frac{x_{50d}}{x_{50}} \quad (2)$$

where is V_d – the air flow through powdered dispenser, m^3/h ; V – the total separator air flow, m^3/h ; x_{50d} – the separation boundary with airtight supply, mm; x_{50} – the separation boundary with unsealed powdered dispenser, mm.

The formula of the relative separation boundary from the relative air flow rate for this experiment will be:

$$\bar{x}_{50} = 1 - 9,61\bar{V}^2 + 0,09\bar{V}. \quad (3)$$

3. Mathematical model

To determine the impact of technological depressurization on the efficiency of separation, consider the mathematical model of the regular cascade separator [13]. At the same time, the cascading classifier will be presented in the form of two separate devices and a power section.

The source material is fed into the power section, where it is perfectly mixed. The material is evenly distributed between the upper and lower devices. We will decompose the continuous process of fractionation of bulk material in a cascading separator. Let's imagine that at any given time there is a discrete number of parallel simple processes. Consider two main re-cleanings: in the first stage in the upper apparatus there is a separation from a fine product of random coarse particles, in the lower apparatus there is a de-dust of coarse material. In the second stage in the lower devices, a coarse product of the first stage of the upper devices is separated from fine particles. In the upper devices there is a clean-up of the fine product of the first stage of the lower devices. In order to implement the material balance and simplify the calculations, we believe that the unaccounted products of the separation of subsequent stages in each section fall into the relevant products of the separation process without additional re-cleaning.

Each separation cascade has its own function of fractional separation. For a fine product, it can be approximated by the Plitt function:

$$F_{Sj}(x_i) = \frac{1}{1 + \left(\frac{x_i}{x_{50j}}\right)^{p_j}}. \quad (4)$$

The output of fine γ_{Sj} and coarse γ_{Lj} products from the cascade can be calculated as:

$$\gamma_{Sj} = \frac{\sum_i r_{Bj}(x_i) F_{Sj}(x_i)}{100}; \quad \gamma_{Lj} = 1 - \gamma_{Sj}, \quad (5)$$

where $r_{Bj}(x_i)$ – is the content of i factions in a product that comes to be re-cleaned in the j -cascade.

The content of the i faction in the fine and coarse product of this cascade is calculated by the following formulas:

$$r_{Sj}(x_i) = \frac{r_{Bj}(x_i) F_{Sj}(x_i)}{\gamma_{Sj}}; \quad r_{Lj}(x_i) = \frac{r_{Bj}(x_i) [1 - F_{Sj}(x_i)]}{\gamma_{Lj}}. \quad (6)$$

The scheme of material flows of the two stage recleaning of the shared material is presented on Figure 3. Here i^* is the power section; γ_{Sj1} , γ_{Sj2} – amount of fine product j section of the first and second stages of cleaning; γ_{Lj1} , γ_{Lj2} – number of coarse product j section of the first and second stages of re-cleaning. If the initial fractional composition, the separation boundary and the separation efficiency of each cascade are known, the total fractional compositions of coarse materials and fine materials can be determined:

$$r_s(x_i) = \frac{r_{S11}(x_i) \gamma_{S11} + r_{S12}(x_i) \gamma_{S12} + \sum_{j=i^*+1}^z (r_{Sj1}(x_i) \gamma_{Sj1} + r_{Sj2}(x_i) \gamma_{Sj2})}{\gamma_{S11} + \gamma_{S12} + \sum_{j=i^*+1}^z (\gamma_{Sj1} + \gamma_{Sj2})}; \quad (7)$$

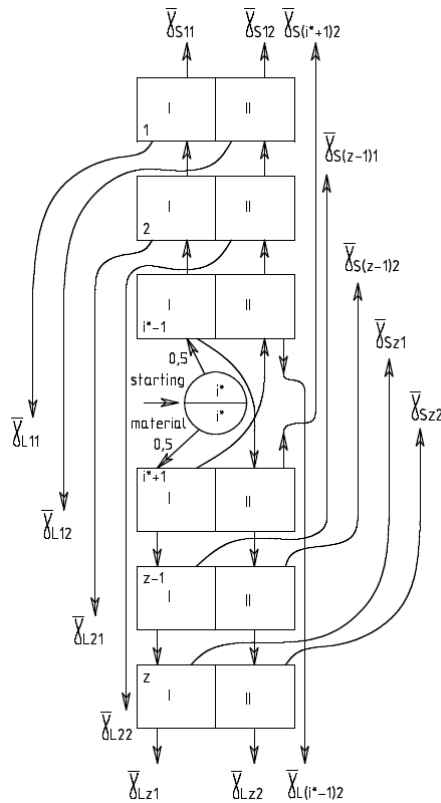


Figure 3. The scheme of material flows of the two stage recleaning of the bulk material.

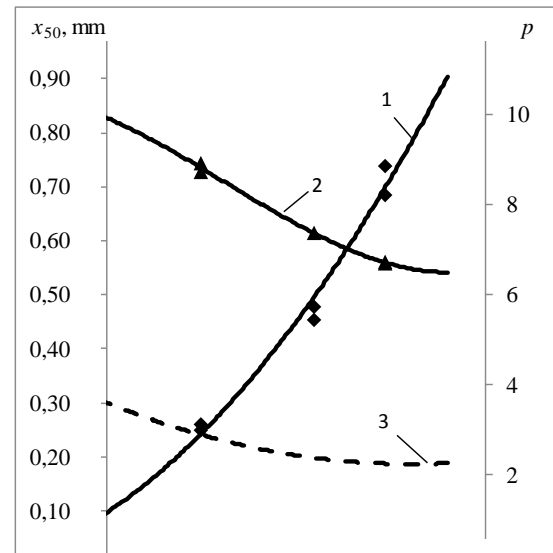


Figure 4. The dependence of the basic process parameters for the fractionation of air velocity: 1 – border; 2; 3 is the sharpness of separation of separator and a separate cascade. Solid lines – approximation of experimental data; dotted line-calculation.

$$r_L(x_i) = \frac{r_B(x_i) - r_S(x_i) \left[\gamma_{S11} + \gamma_{S12} + \sum_{j=i^*+1}^z (\gamma_{Sj1} + \gamma_{Sj2}) \right]}{\gamma_{Lz1} + \gamma_{Lz2} + \sum_{j=1}^{j=i^*-1} (\gamma_{Lj1} + \gamma_{Lj2})}; \quad (8)$$

Total output of fine material according to Figure 3:

$$\bar{\gamma}_S = \bar{\gamma}_{S11} + \bar{\gamma}_{S12} + \sum_{j=i^*+2}^z \bar{\gamma}_{Sj1} + \sum_{j=i^*+2}^z \bar{\gamma}_{Sj2} + \bar{\gamma}_{S(i^*+1)2}, \quad (9)$$

where is

$$\bar{\gamma}_{S11} = \frac{1}{2} \prod_{j=1}^{i^*-1} \gamma_{Sj1}; \quad (10)$$

$$\bar{\gamma}_{Sj1} = \frac{1}{2} \gamma_{Sj1} \prod_{k=i^*+1}^j \gamma_{Lk1}; \quad (11)$$

$$\bar{\gamma}_{S12} = \frac{1}{2} \gamma_{S(i^*+1)1} \prod_{k=1}^{i^*-1} \gamma_{Sk2}; \quad (12)$$

$$\bar{\gamma}_{Sj2} = \frac{1}{2} \gamma_{Sj2} \gamma_{L(i^*-1)1} \prod_{k=i^*+1}^{j-1} \gamma_{Lk2} ; \quad (13)$$

$$\bar{\gamma}_{S(i^*+1)2} = \frac{1}{2} \gamma_{L(i^*-1)1} \gamma_{S(i^*+1)2} . \quad (14)$$

Total output of coarse material:

$$\bar{\gamma}_L = 1 - \gamma_S . \quad (15)$$

Given that the separation boundary is directly dependent on the flow velocity, it will be different in the proposed model for each of the two classifiers. The sharpness of the separation is determined by the design of the device and is the same for each cascade. If experimental data is inserted into the presented model, it will be possible to determine the dependence of the main technological parameters of the fractionation process on the velocity of airflow (Figure 4). If the air velocity varies from 2 to 4.5 m/s, the separation boundary for this classifier is described by the expression:

$$x_{50} = 0,053w^2 - 0,057w ; \quad (16)$$

total indicator of the sharpness of the separation:

$$p = 0,18w^3 - 1,6w^2 + 3w + 8,8 ; \quad (17)$$

indicator of the sharpness of the separation of the individual cascade:

$$p = 0,23w^2 - 2,1w + 6,8 . \quad (18)$$

4. Applying a mathematical model

Consider the application of the proposed method in order to calculate the granulometric composition of the enriched quartz sand fraction (0.7–5 mm). The source material is sand 0–5 mm. We will predict the operation of the air separator at varying amounts of the relative air flow through the depressurized feeder. The limit on class content minus 0.315 mm in enriched sand is no more than 1.5 %. In the mathematical model (Figure 3), the rate of separation of each section in the upper and lower devices will be the same and will be determined by equation (18). The separation boundary for each cascade in the top classifier will be determined by the expression (16). In the lower devices, the separation boundary will depend on the amount of relative depressurization (3) and, taking into account (16), will be equal to

$$x_{50d} = (0,053w^2 - 0,057w)(1 - 9,61\bar{V}^2 + 0,09\bar{V}) . \quad (19)$$

Relative air flow rate through the powdered dispenser affects the velocity of air flow in the upper separator and the output of the finished product. Figure 5 shows this effect when performing a class content limit of minus 0.315 mm in enriched sand no more than 1.5 %. At a constant velocity of airflow through the upper classifier with an increase in the value of relative depressurization increases the content of classes minus 0.315 mm in enriched sand (Figure 6).

5. Conclusions

Laboratory tests and analysis of the mathematical model have shown that unauthorized air flow through the powdered dispenser reduces the efficiency of the powder fractionation process. With the limits on the content of fine fractions in the finished material to solve the problem, you need to increase the total air flow rate through the classifier, which leads to a decrease in the output of the product. With a fixed amount of air flow and depressurization, there are no established restrictions on the fractional composition of the finished material. As shown in Figure 5, the maximum relative air flow rate through the powdered dispenser should be no more than 10–15 %. At the same time, the total air flow rate increases by 3–6 %, and the reduction in the mass of output product is projected by no more than 2 %. The proposed mathematical model allows to carry out any technological calculations of cascading separators.

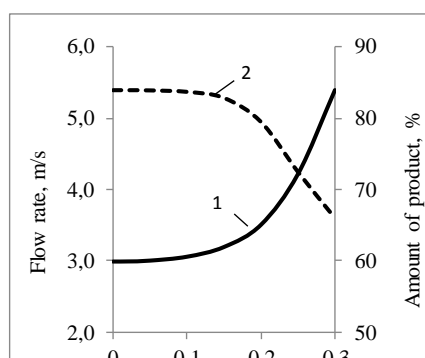


Figure 5. Dependence of relative air flow through the powdered dispenser on the velocity of airflow and output of the finished product: 1 – Air flow velocity, 2 – Output of the finished product.

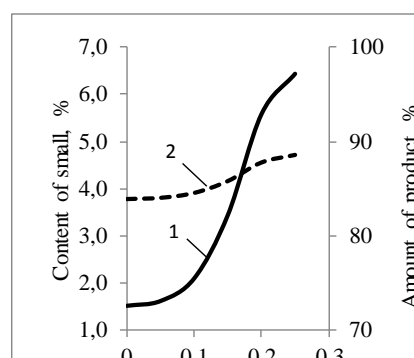


Figure 6. Effect of relative air flow through the powdered dispenser on class content minus 0.315 mm in enriched sand: 1 – Content minus 0.315 mm, 2 – Output of the finished product.

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